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Mathematical and numerical modelling of soiling effects of photovoltaic solar panels on their electrical performance

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Abstract. With time, the photovoltaic solar panels naturally soiled from dust and other elements. These soils prevent light to reach solar cell and can reduce the long-term profitability. The study demonstrates the soiling effect on the electrical characteristics of panels, productivity and performance. A model simulation was developed in this direction in order to quantify and compare the performance of clean and dirty panels, the dust particles have been considered as spheres with an elliptical shadow on the panel. The results prove a power loss of 40% of a 0,224 mg/cm² dust deposition in comparison with a clean panel at the maximum operating point MPP. This study describes the identified critical parameters governing the fouling of the PV panels.

Keywords: photovoltaic panel; soiling effect; simulation; electrical performance

1. Introduction

The soiling effect of PV panels is a complicated and sophisticated problem since the phenomenon of dirt fouling is random and probabilistic. Many studies have observed the reduced power performance of PV module due to dust deposition and others environmental influences [1]. *Elminir et al.* confirmed the good reliance of dirt depositing, the transmittance and the power received [2]. *Hottel et al.* [3] proved a loss of 1% in solar radiation caused by dust deposition on glass tilted by an angle of 30° with a maximum degradation of 4.7%. *El Shobokshy et al.* have shown that the short-circuit current is decreased by 20% for a density of 28 g/m² of carbon nanoparticles [4,5]. *Mani and Pillai et al.* [6] have studied many climatic zones and their dust deposition level, and many recommended cleaning methods for each zone [7]. There is a theoretical model [8] for the simulation of a system with an opaque dust layer and a thickness varying from 0 µm to 5 µm, where 0 µm represents a cleaned module, and 5 µm represents a dirty module. This dust is formed of several thousand of small grains with different sizes placed on



glass. The study investigates the influence of dust on the optical transmission of photovoltaic module compared to a clean module. According to the results an attenuation close to 90% has been detected [8]. There are different factors that affect the dust deposition, such as grain size, physical properties of module surfaces, type of glass, texture or antireflection, wind speed, and many other factors [9]. Also there are many types of pollutants (dust) that affect the performance of the modules, and various experiences have shown that each type of dust corresponds to a very specific voltage output as described in [10]. It is found that the most influential dust at the output voltage of the photovoltaic panel is ash with a reduction of 30%, and the least considerable type of dust is sand with a reduction of 4%. The study [11] revealed the impact of cement particles to be the most important, with a density of 73 g/m² of cement dust deposition resulting in an 80% decrease in PV short-circuit voltage, and the atmospheric dust with a diameter of 80 µm to 250 g/m², reduced the short-circuit current by 82%. Fine carbon particles (5 µm) had the most detrimental effect on PV efficiency. Also the finer particles have a greater impact than coarser particles on PV performance, for the same type of dust [11].

2. Mathematical model of soiling

2.1. Soiling modelling

The dust layer has a negative effect on the transmission of light through photovoltaic glazing surface, and it is studied by a mathematical model. For this, the different equations and the mathematical model are presented to calculate the particle transmittance. This model is based on a study by *Ahmed. Y et al.* [12]. The transmission of light at different angles of incidence for glass samples covered with dust particles will be calculated and compared with the mathematical model [12], where the transmittance for inclined angle of incidence $\tau_b(\theta)$ is:

$$\tau_b(\theta) = 1 - Q_e \cdot S_c(\theta) \quad (1)$$

With $S_c(\theta)$ is the total covered area, and Q_e is the efficiency extinction of light.

The beam radiation component I_b must be modified by the beam transmission factor $\tau_b(\theta)$. Therefore, the component due to dust particles $I_b(\theta)$:

$$I_b(\theta) = I_b \cdot \tau_b(\theta) \quad (2)$$

2.2. Simulation results of soiling modelling

The previously described mathematical model is validated by the model found in the article [12], as can be seen in figure 1. As the amount of dust installed on the surface of the panels decreases, beam light transmission reaches zero at very high angles of incidence. Furthermore, at high dust, the transmittance reaches zero at lower angles of incidence. We compared the radiation transmittance between the soil model described in [12] and our model. This comparison is made by taking two dust deposition densities of 0.224 mg/cm² and 0.02 mg/cm² as shown in Table 1. For the first soil density 0.224 mg/cm², the minimum relative error found is 0.88%, and increasing the inclination angle θ from 20° to 60°, the error reached a maximum value of 5.66. %. And for a second soil density 0.02 mg/cm², the minimum error is 0.2% for an inclination angle of 20°, and the maximum error is 1.09% for an angle equal to 78°.

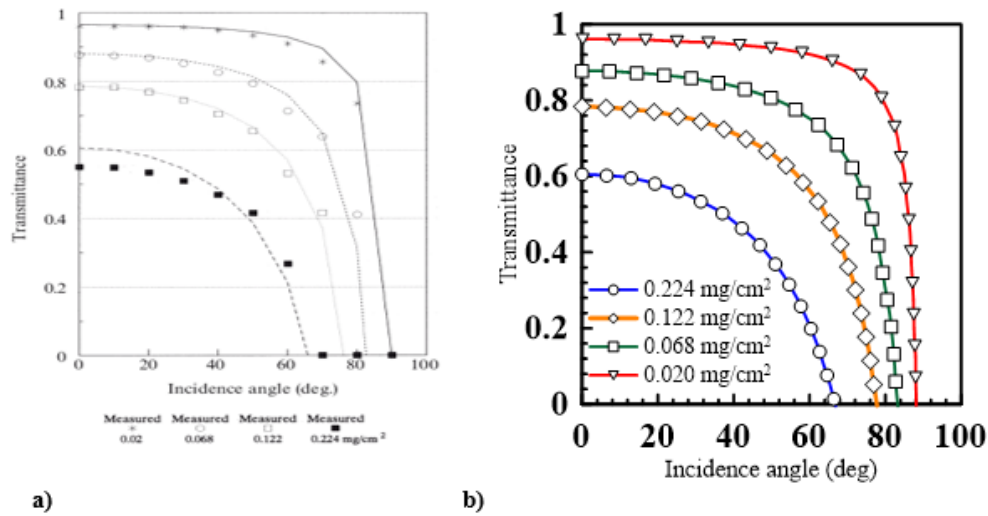


Figure 1. Transmittance for different angles of incidence and dust masses, a) for model [12] and b) our calculated simulation.

The difference does not exceed 6%. This difference is due to uncertainty in calculation when reading the curves. From the comparison, it can be deduced that the calculation error is important when the value of the soil density is large.

Table 1. Comparison between calculated transmittance and that of the soiling model.

| Density (mg/cm ²) | | θ (°) | 20 | 30 | 40 | 50 | 60 |
|----------------------------------|------------|----------------|------|-------|-------|-------|------|
| 0.224 | τ (%) | Dust model | 58.1 | 54.5 | 48.6 | 38.6 | 21.2 |
| | | Our results | 58.6 | 55.4 | 50.03 | 39.1 | 20 |
| | | Relative error | 0.88 | 1.65 | 2.94 | 1.3 | 5.66 |
| | | (%) | | | | | |
| 0.02 | τ (%) | θ (°) | 20 | 40 | 60 | 70 | 78 |
| | | Dust model | 96.5 | 95.7 | 93.3 | 89.9 | 82.1 |
| | | Our results | 96.3 | 95.54 | 93.37 | 90.61 | 83 |
| | | Relative error | 0.2 | 0.16 | 0.07 | 0.78 | 1.09 |
| | | (%) | | | | | |

3. Mathematical model of photovoltaic panel

3.1. Photovoltaic panel modelling

The mathematical model of solar cells is essential for the study of performance optimization operation. The photovoltaic module is represented by an equivalent circuit with experimental parameters from the current-voltage characteristic. These parameters are not usually measurable quantities, they must be calculated by systems of equations at different operating points given by the manufacturer or derived from the direct measurement on the module. This modeling is a crucial step and has led to diversification in the models proposed by the different researchers. Their differences are generally in the number of diodes, the finite or infinite shunt resistance, the ideality factor, as well as the numerical methods used to determine the various parameters. An electrical model of the photovoltaic cell has been presented; it is a real model with both series and parallel resistors (Shunt). This is the model on which builders rely

by giving the technical characteristics of their solar cells. It is also considered satisfactory and even a reference for manufacturers to typically catalog solar modules [13]. It takes into account the voltage losses expressed by the R_s series resistor, and also the current leaks expressed by a parallel resistor R_{sh} as seen in figure 2:

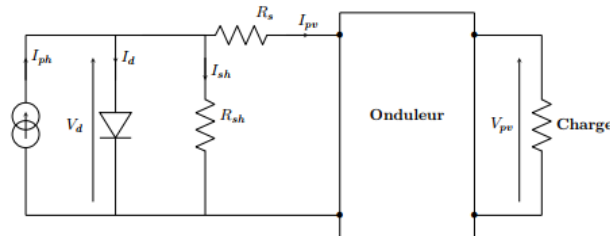


Figure 2. Equivalent circuit of a solar cell model with a diode.

3.2. Simulation and results of panel modelling

There are several factors influencing the photovoltaic system such temperature, irradiances, dust deposition, humidity and wind speed, which can impact the performance of the photovoltaic cell [14–18]. The Influence of dust is studied and shows that the dust deposition on panels affects all the electrical characteristics of the PV system; current, voltage and power. The figure 3 shows the evolution of the current as a function of the voltage of a clean panel with zero soiling density and under standard conditions STC (0 mg/cm^2 , 25°C and 1000 W/m^2), also the evolution of the dirty panel with a density of 0.224 mg/cm^2 . The two curves kept the same shape of exponential decline, and the density of 0.224 mg/cm^2 had reduced the current from 17.5 A to 10 A at the peak of operating point (MPP) resulting in a power loss of 38.88% . In addition, the figure 5 shows the evolution of the power according to the voltage, making also a comparison of the photovoltaic system in cleaned and dirty state. The dirt reduces the power from 10 kW to 6 kW at the maximum operating point MPP which gives a power loss of 40% .

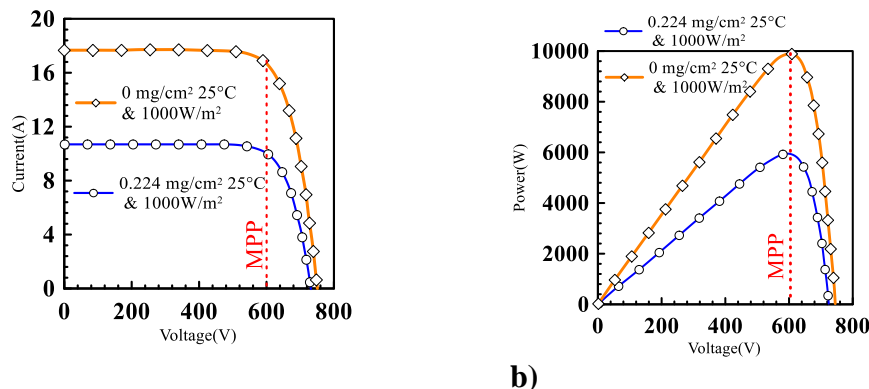


Figure 3. a) Influence of dust on the current- voltage curve. b) Influence of dust on the power-voltage curve.

4. Conclusion

In this work, the problem of soiling and its effect on the panels has been presented as well as the various factors influencing the phenomenon of soiling. The dust accumulates on the panels due to gravitation, and glued when it mixes with water droplets already deposited on panels. It has been shown that the solar radiation received can be evaluated mathematically. This will help PV manufacturers to evaluate more precisely this radiation, as well as the predictive ability of existing solar models that can increase panel performance. In another perspective, the mathematical model performed could be improved if a statistical study is developed of the phenomenon of soiling. It can be concluded that soiling has a

detrimental and serious effect on the power generation of PV plants, with a power loss of 40% with a dust deposition of 0,224 mg/cm².

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